ICE BALL IMPACT RESISTANCE OF HEAT-AGED TPO ROOFING MEMBRANES

By Sarang Bhawalkar, Tammy Yang, and Thomas J. Taylor

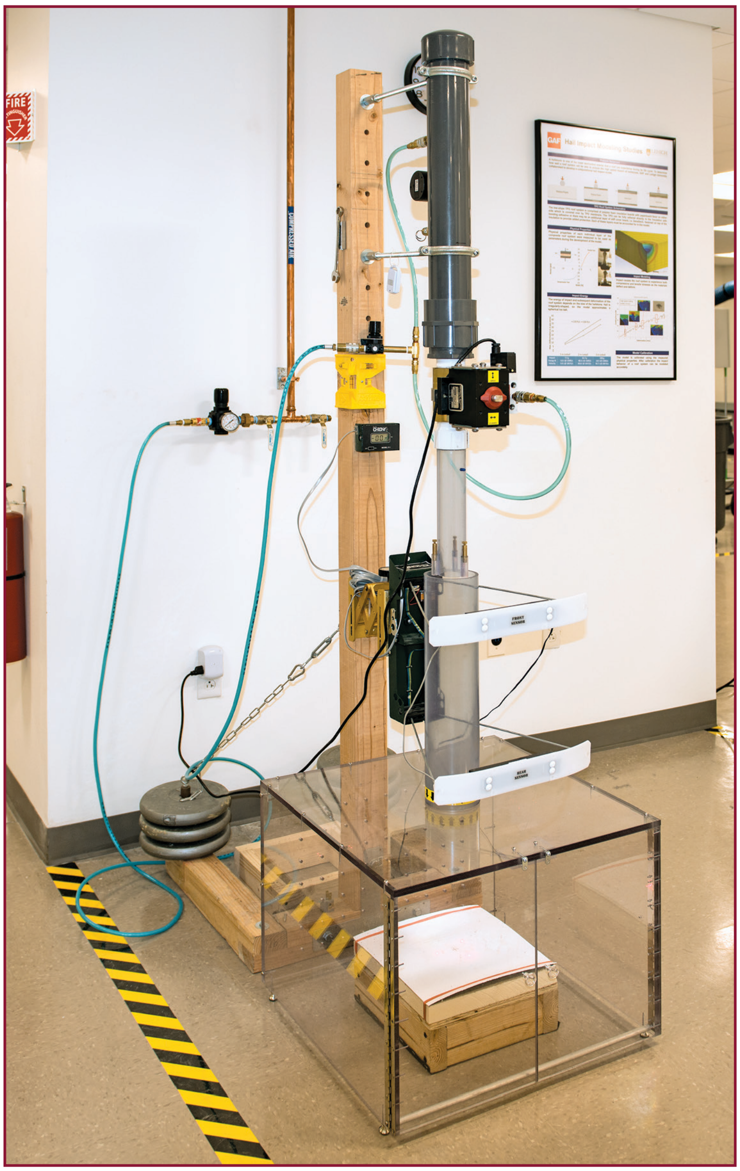

Figure 1 – Launcher used to direct freezer ice balls downwards to impact a simulated roof system.

INTRODUCTION

Single-ply membranes now represent over 50% of the U.S. commercial roofing market, with thermoplastic polyolefin (TPO) being the most often used. A recent study of TPO suggests that today's membrane could perform well past 20 years, and some manufacturers offer warranties out to 35 years for specific high-performance versions.[1,2] The weathering of TPO has been examined in many laboratory studies and field evaluations. Performance has generally been assessed in terms of membrane cracking, surface erosion, and other characteristics that could lead to water intrusion.

Recently, the authors evaluated the puncture resistance[3] and ice ball impact resistance of TPO membranes.[4,5] Using 2-inch-diameter ice balls and following a procedure similar to that of FM 4473, *Specification Test Method for Impact Resistance of Rigid Roofing Materials by Impacting with Freezer Ice Balls*,[6] they found that as long as impact was not above a fastener, the membrane was not punctured. They recommended the use of fully adhered systems and adhered high-density (HD) polyisocyanurate (polyiso) coverboard to minimize damage to either the membrane or the underlying insulation. It was noted that HD polyiso suffers less damage after ice ball impact compared with gypsum cover board.

The previous work used unaged material, with all testing being done indoors at room temperature. Cullen noted, "The results of testing new materials may not be valid since the hail impact resistance of many roofing materials changes upon exposure to weather."[7] Later, Crenshaw and Koontz also questioned the focus on testing only new materials.[8] More recently, Graham has also cautioned, "Impact resistance testing is done on new, unweathered products at standard room temperatures." However, he noted that hail rarely impacted new roofs and, additionally, often occurred during decreasing temperatures.[9]

This work builds on our previous focus on the ice ball impact resistance of TPO systems and examines the effects of accelerated aging. As noted by Graham, it is important to recognize that the relationship between hail and ice ball impact resistance hasn't been established. Ice ball impact testing attempts to rank the performance of materials, but their correlation to hail resistance is not known.

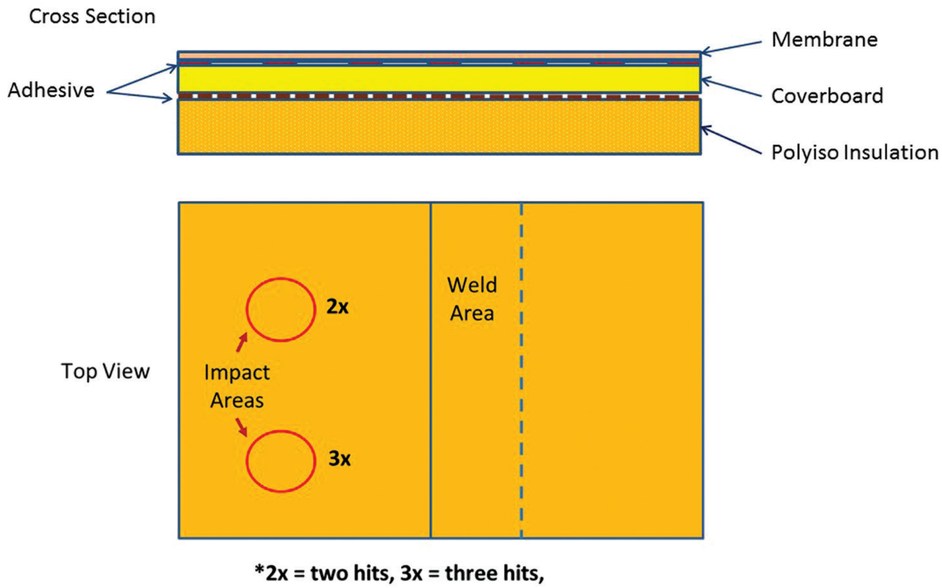

Figure 2 – Schematic of the roof system tested.

IMPACT TEST PROCEDURE

This work uses freezer ice balls with a procedure similar to the FM 4473 test method.[10] The standard was originally written for steep-slope roofing and recently has been adapted to test low-slope roofing systems. For this study, a 1 x 1-ft. wooden deck was used as backing for the sample. The sample, which had the same dimensions as the deck, was placed on the deck and hit with consecutive 2-in.-diameter premolded ice balls at target kinetic energy between 23.75 and 26.13 ft.-lb. force (criteria for FM Class 4), with a maximum distance of 0.5 in. between impacts. One spot was hit with two consecutive ice balls, while another spot was hit with three. The criteria for FM Class 4 requires two consecutive ice balls. Any splits, fractures, or punctures in the membrane were regarded as a failure.

The ice ball launcher, shown in *Figure 1*, used compressed air as the accelerant. Ice ball speed was measured using a Master Chrony Model F1 monitor.

SYSTEMS TESTED

Our previous studies clearly showed that ice ball impact above fasteners resulted in a puncture of the membrane, regardless of membrane thickness. Also, using 2-in.-diameter ice balls, it was found that a cover board was necessary to reduce or eliminate damage to the polyiso insulation. For this study, only fully adhered membrane and adhered HD polyiso cover board (ASTM C1289, Type II, Class 4) over 2-in. polyiso (ASTM C1289, Type II, Class 1, Grade 2) were evaluated. This is shown schematically in *Figure 2*.

The membranes were all 60 mils thick, chosen because this represents a large majority of the TPO market. A standard membrane and one specifically designed for high-temperature resistance and long life in demanding applications were tested. Smooth and fleeceback versions of the two membranes were tested, with the fleece being 3.5 oz. in weight. Two types of membrane adhesives were used—solvent-based (SBA) for the smooth, and water-based (WBA) for the fleeceback membranes.

ACCELERATED AGING OF MEMBRANE

Testing was carried out for two different accelerated aging scenarios. The aging used heat, a leading contributor to TPO degradation.[1,2] It is important to note that in real-world installations, membranes are subjected to many other stresses, including mechanical, wind, thermal, and light-based. The correlation of high-heat exposure to real-world thermal aging used in this work is not intended to create a warranty as to the performance of any system tested. The intent is to provide a relative ranking of systems.

In the first scenario, the objective was to look at membranes that were aged for a certain amount of time and then impacted. The TPO samples were heat-aged at 275°F (135°C) for various times up to an equivalent of 30 years' thermal exposure, and then impacted. In the second scenario, the objective was to examine systems that were impacted while unaged and then impacted again after having heat-aged for 30 years' equivalence. In the latter case, prior to heat-aging, each membrane was loose-laid over HD polyiso cover board and polyiso insulation and subjected to two consecutive ice ball impacts at the same location. These locations were marked on the membrane, cover board, and polyiso. After heat-aging the membranes, the components were reassembled into the final fully adhered systems for testing. Each sample was impacted again on the spots initially hit. The overall procedure is shown schematically in *Figure 3*. The insulation was not subjected to heat-aging because any correlation with service life is not known.

Note that the standard fleeceback membrane showed surface cracking after 130 days of heat-aging (30-year thermal exposure equivalence) and, therefore, could not

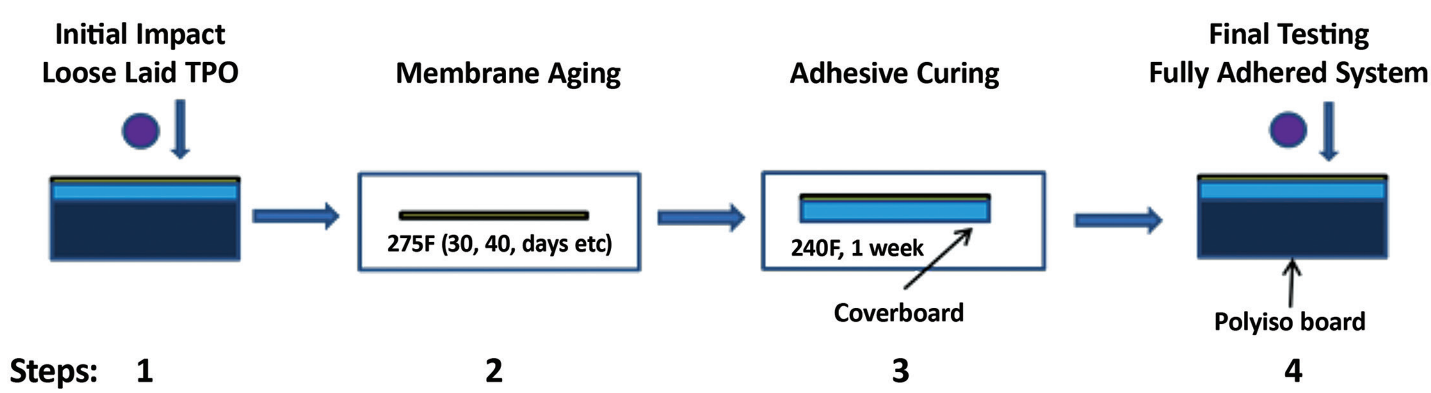

Figure 3 – Accelerated aging and sample construction shown schematically. Half of the samples were not impacted prior to aging.

be tested. In practice, roofing membranes that showed signs of cracking would be repaired or replaced.

RATING THE EFFECT OF ICE BALL IMPACT

FM 4473 calls for a pass/fail rating based on whether or not the membrane has been visually punctured. Our previous studies have shown that—depending on the system—cover boards and/or the polyiso insulation can also be damaged by ice ball impacts. Therefore, the three components were rated pass/fail based on the following:

- Membrane – the absence of a crack or other breach of the surface (pass)
- Polyiso insulation – the absence of any split or break in the top paper facer (pass)
- HD polyiso cover board – the absence of any split or break in the bottom glass facer (pass)

All examinations were done visually, without magnification.

IMPACT RESISTANCE

After Accelerated Heat-Aging of Membrane

The results of ice ball impacts on the TPO systems are shown in *Table 1*. All of the systems performed very well, although some slight differences do exist.

At the 20-year thermal aging equivalence point, the smooth systems showed cracking of both the cover board and insulation facers after three consecutive impacts (but all passed after two impacts). However, at the 30-year point, no damage to either was visible. This result implies that the membrane properties change in a nonlinear manner during aging. It has previously been noted that there are two degradation mechanisms: breakdown of the polymer chains and crosslinking. The former could be expected to soften the material, while the latter would make the membrane more rigid and ultimately brittle.

After Accelerated Heat-Aging of Previously Impacted Membrane

The results of ice ball impacts on the membrane systems that had been initially impacted and then aged are shown in *Table 2*.

As can be seen, the results differ from those shown for membranes that had not initially been impacted. The 10-year-old equivalent samples showed some failures, which suggests that large ice ball impacts do affect the membrane, even when no damage is visible. The membrane was not visibly damaged, but the underlying cover board and polyiso for the smooth membrane system were. If confirmed, this is an important finding that might have significant implications for roofs exposed to similar impacts.

As with the results obtained without prior impact, there are some indications of a reduction in impact resistance at the longer-lifetime equivalents. The previous work showed that fleeceback membranes outperform the smooth equivalents; however, that is not always the case for the aged membranes.

CONCLUSIONS

1. In general, the aged TPO tested in this study performed very well in ice ball impact testing, even at the 20-year heat-aged equivalence point.
2. The fleeceback TPO membrane is specifically designed for demanding situations in terms of ice ball impact resistance, even at the 30-year heat-

aged equivalence point.

3. For the best ice ball impact resistance, the fleeceback version of the long-life TPO, with the HD polyiso cover board, performed best.
4. When viewed together with the prior work, the results clearly indicate that the best-performing system is fully adhered and is comprised of fleeceback long-life TPO and adhered high-density polyiso cover board. It is very important to ensure that fasteners are not used immediately below the membrane.
5. Results for heat-aged membranes that had already been impacted suggest that, even when not visible, 2-inch ice ball impacts can affect the performance of the membrane over the long term.

Days at 275 F	Equivalent Age (yrs)	60 mil Smooth with SBA						60 mil Fleeceback with WBA					
		Standard			Long Life			Standard			Long Life		
		M	C	I	M	C	I	M	C	I	M	C	I
30	10	P	P	P	P	P	P	P	P	P	P	P	P
40	15	P	P	P	P	P	P	P	P	P	P	P	P
80	20	P	P*	P*	P	P*	P*	F	P	P	P	P	P
130	30	P	P	P	P	P	P	-	-	-	P	P	P

Table 1 – Impact resistance of heat-aged TPO systems.
M – Membrane, C – Cover board, I – Insulation.
** Passed after two impacts, but failed after three.*

Days at 275 F	Equivalent Age (yrs)	60 mil Smooth with SBA						60 mil Fleeceback with WBA					
		Standard			Long Life			Standard			Long Life		
		M	C	I	M	C	I	M	C	I	M	C	I
30	10	P	F	F	P	P*	P	P	P	P	P	P	P
40	15	P	P	P	P	P	P	P	P	P	P	P	P
80	20	P	P	P	P	P	P	P	P*	P	P	P	P
130	30	P	P*	P*	P	P*	P*	-	-	-	P	P	P

Table 2 – Impact resistance of previously impacted and then heat-aged TPO systems.
M – Membrane, C – Cover board, I – Insulation.
** Passed after two impacts, but failed after three.*

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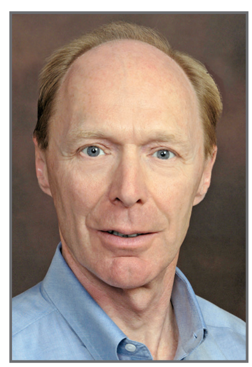

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Tom Taylor received a bachelor of science with honors and a PhD in chemistry from Salford University, UK. He has over 25 years of experience in the building products industry, all with manufacturing organizations. With a long focus on product development, he holds approximately 35 patents. Taylor is responsible for overseeing GAF's building and roofing science initiatives. He has been with GAF for ten years and has prior experience with other leading glass, roofing, and insulation manufacturers.